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Fluids and Combustion Facility Document

FIR Optics Bench Human Factors Study

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(Official signatures on file with the FCF Project Control Specialist)

Prepared By:

Vicki J. Smith
Human Factors Engineering Intern
Embry-Riddle Aeronautical University
& Rensselaer Polytechnic Institute

Concurred By:

Dennis W. Rohn
FCF Chief Engineer
Systems Engineering Division
Glenn Research Center

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1.0 INTRODUCTION

1.1 Purpose

The National Aeronautics and Space Administration (NASA) is developing a modular, multi-user experimentation facility for conducting fluid physics and combustion science experiments in the microgravity environment of the International Space Station (ISS). This facility, called the Fluids and Combustion Facility (FCF), consists of three test platforms: the Fluids Integrated Rack (FIR), the Combustion Integrated Rack (CIR), and the Shared Accommodations Rack (SAR). The primary data that is gathered for these science experiments is generated by a set of diagnostics, which are systems that illuminate and image the science phenomenon being studied. Some of these diagnostics are provided as standard by the FCF and others are unique to the science experiment. In the FIR, these diagnostics, and test cells containing the science experiment being studied, are mounted to an optics bench. The optics bench allows flexible reconfiguration of the diagnostics to support a broad spectrum of science.

This document gives the results of a Human Factors study of the FIR Optics Bench labeling and crew procedures for installing this equipment on the FIR Optics Bench. The hope is that the data gained during this experiment might provide useful information to improve the Human Factors Characteristic designs of the FIR Optics Bench. The human factors characteristics related to the optics bench focus on the speed/accuracy requirements, operational environment, and training requirements. Due to the limited time factor allotted for set-up and in order to assure correct configuration of the diagnostics, it is pertinent that the crewmember be able to apply the diagnostics for each science experiment to the optics bench in a simple manner (avoiding extreme mental and physical workloads). In accommodating these requirements one must look at how the information will be presented to the astronauts. This information must be presented in such a way, which provides assembly of each experiment in an accurate and efficient manner. This report is a compilation of the data and analysis of the experiment that was conducted to compare the different ways of presenting the needed information in relation to time and accuracy of the placement.

1.2 Scope

This report covers the experiment activities from July 12, 2001 to July 27, 2001. Details of the experiment can be found in the appendices of this document.

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2.0 REFERENCES

2.1 Reference Documents

Document Number	Document Title
SSP57000	Pressurized Payloads Interface Requirements Document
---	Research Methods: A Process of Inquiry - Anthony Graziano / Michael Raulin
---	Basic Statistics for the Behavioral Sciences – Gary Heiman

2.2 Records and Forms

N/A

2.3 Acronyms

Acronym	Definition
ANOVA	analysis of variance
CIR	Combustion Integrated Rack
DCM	diagnostics control module
FCF	Fluids and Combustion Facility
FIR	Fluids Integrated Rack
HFR	high frame rate
IAM	image acquisition module
ISS	International Space Station
NASA	National Aeronautics and Space Administration
OM	optics module
SAR	Shared Accommodations Rack

2.4 Definition of Terms

These definitions were collected from two sources: Research Methods – A process of Inquiry (Graziano/Raulin) and Basic Statistics for the Behavioral Sciences (Heiman).

Term	Definition
Analysis of variance	Statistical procedure used to analyzed for mean differences two or more groups. ANOVAs compare the variability between groups with the variability within groups. Many variations of analysis of variance are possible, including repeated measures ANOVAs and factorial ANOVAs.
ANOVA summary table	Table that organizes the results of an analysis of variance computation. For each source of variation the appropriate degrees of freedom (df), sums of squares (SS), mean square (MS), and F-ratios (F) are listed.

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Term	Definition
Between-subjects design	Research design using two or more groups in which each subject appears in only one of the groups.
Carry-over effects	These are the effects of a subject participating in one condition on his or her performance in all subsequent conditions. Carry-over effects occur only when subjects appear in more than one experimental condition (i.e., in within-subjects design).
Confounding variable	Any uncontrolled variable that might affect the outcome of a study. A potential confounding variable exists only (1) there is a mean difference between the groups on the variable and (2) there is a correlation between the variable and the dependent measure.
Counterbalancing	Control procedure used in within-subjects designs to control for sequencing effects. It is most practical when there are a small number of conditions in the study.
Data	Plural noun that refers to information gathered in research. Research conclusions are drawn on the basis of an evaluation of the data gathered as part of the study.
Degrees of freedom (df)	Statistical concept. One degree of freedom is lost each time a population parameter is estimated on the basis of a sample of data from the population. The distribution of most statistics (t, F, and so on) are tabled by degrees of freedom (df).
Dependent variable	Variable that is hypothesized to have a relationship with the independent variable.
Eta squared	The proportion of variance in the dependent variable that is accounted for by changing the levels of a factor, and thus the measurement of effect size, in the sample.
F-ratio (or F-test)	A test statistic computed by taking the ratio of two variances. F-ratios are used most often in analysis of variance where the two variances estimates are an estimate based on (1) the difference between group means and (2) the difference among subjects within groups.
General control procedures	Control achieved through preparation of settings, careful response measurement, and replication.
Graphs	A means of presenting data visually.
Independent variable	Any variable in research that defines separate groups of subjects on which the dependent measure is taken. Subjects may be assigned to these groups on the basis of either (1) some preexisting characteristics (differential research) or (2) some form of random assignment (experimental research)
Individual differences	Natural differences between people on any variable. Individual differences between people on a dependent measure tend to obscure effects of an independent variable on the dependent measure(s).
Informed consent	Critical principle in the ethical treatment of subjects. Subjects have the right to know exactly what they are getting into and to refuse to participate.
Informed consent form	A form that is designed specifically for each research project and is signed by each human subject prior to the beginning of the study. The informed consent form must present enough detail about the study and its risks to permit subjects to make informed decisions about their participation.

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Term	Definition
Internal validity	Accuracy of the research study in determining the relationship between the independent and the dependent variables. Internal validity can be assured only if all potential confounding variables have been properly controlled.
Mean	Arithmetic average of scores. The mean is the most commonly used measure of central tendency but should be computed only for score data.
Mean square (MS)	In analysis of variance (ANOVA), the mean square is a variance estimate. Several different mean squares are computed in any ANOVA. It is the ratio of mean squares that is the F-ratio and constitutes the inferential statistical test.
Median	Middle score in a distribution.
Null hypothesis	States that the subjects from each group are drawn from populations with identical population parameters. The null hypothesis is tested by inferential statistics.
Observation	Empirical process in which data about the phenomenon of interest are gathered and reported. Careful observation is a central task in all research.
One-Way ANOVA	Statistical procedure that evaluates differences in mean scores of two or more groups where the groups are defined by a single independent variable.
Population	Any clearly defined set of objects or events (people, occurrences, animals, and so on). Populations usually represent all events in a particular class (e.g., all college students, etc)
Practice effects	Any change in performance on a dependent measure that results from previous exposure of the subject to the measurement procedure.
P-value	The probability of obtaining the statistic (e.g., t or F) or a larger statistic by chance if the null hypothesis is true. Statistical analysis programs routinely compute p-values in addition to the test statistic.
Questionnaire	A psychological instrument that lists questions to be asked of subjects.
Relationship	Any connection between two or more variables. In research there are many types of relationships, from simple contingencies to established causal relationships.
Reliability	Index of the consistency of a measuring instrument in repeatedly providing the same score for a given subject. There are many different types of reliability, each referring to a different aspect of consistency. Types of reliability include interrater reliability, test-retest reliability, and internal consistency reliability.
Repeated-measures ANOVA	Statistical procedure to evaluate the mean differences between two or more conditions where the same subjects contribute scores under each condition. The repeated measures ANOVA takes into account the fact that the same subjects appear in all conditions.
Repeated-measures design	Any research design in which subjects are tested more than once. Examples of such designs are pretest-posttest designs, within-subjects designs, and time-series designs.
Repeated-measures factorials	Factorial design in which subjects are within-subject factors. Each subject is tested under every possible combination of conditions in the design.
Replication	To repeat a study with either no changes at all in the procedure (exact replication) or carefully planned changes in the procedure (systematic or conceptual replication).

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Term	Definition
Representative sample	Sample of subjects that adequately reflects the characteristics of the population from which the sample is drawn.
Sequencing effect	Potential confounding variable in research involving repeated or multiple measures. Sequencing effects are the effects on the performance of subjects in later conditions as a consequence of their having previously participated in other conditions.
Statistical significance	A finding is said to achieve statistical significance if it is unlikely that such a finding would have occurred by chance alone.
Statistical validity	Accuracy of conclusions drawn from a statistical test. To enhance statistical validity, one must meet critical assumptions and requirements of a statistical procedure.
Sum of squares	Sum of the squared differences from the mean. The sum of squares is the numerator in the variance formula.
Validity	Major concept in research that has several specific meanings (internal validity, external validity, construct validity, statistical validity). In a general sense, validity refers to the methodological and/or conceptual soundness of research (e.g., in the case of an experiment, a question regarding validity is "Does this experiment really test what it is supposed to test?")
Within-subjects design	Research design in which individual differences are controlled by having the same subjects tested under all conditions
Within-subjects factorial	A factorial design in which each subject appears in each condition.
Within-subjects factors	Independent variables in factorial designs in which each subject is tested under all conditions

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3.0 EXPERIMENT

The experiment was designed using an apparatus to simulate the actual FIR optics bench. Each participant in the experiment evaluated options in the optics bench labeling and directions. Statistical methods were used to evaluate the results.

3.1 Method

This experiment was conducted using a Within-Subjects design. This is a design in which individual differences, which are the single largest contributing factors to error variance, are controlled by having the same subjects/participants tested under all of the different conditions. In a Within-Subjects Design it is important to prevent sequencing effects also known as confounding variables, by varying the order in which the different conditions are presented, which is also known as counterbalancing. In a complete counterbalancing: (1) each participant is exposed to all of the conditions of the experiment, (2) each condition is presented an equal number of times, (3) each condition is presented in equal # of times in each position, and finally (4) each condition precedes and follows each other condition an equal number of times. (See Appendix E for the Counterbalancing method used.) The counterbalancing method was implemented in the FIR Optics Bench Experiment by using four different experiment setups – A, B, C, and D. By using these four different experiment set-ups, it is hoped to prevent any learning carryover effects that might have occurred if the participants had the same experiment setup design for the four different trials.

3.2 Participants

The 24 participants involved in the FIR Optics Bench experiment were a combination of student interns at NASA and NASA Employees, of which 54% were interns and 46% were NASA employees. Of the 24 participants, eight were female and 16 were male. The participants' ages ranged from 16-54 years, with a mean age of 27.7 years and a median age of 23 years. The participants' backgrounds covered a variety of fields including, aerospace engineering, mechanical engineering, systems engineering, operations engineering, integration engineering, electrical engineering, chemical engineering, physics, management information systems, project manager, a commercial pilot and a high school student interested in either business or engineering.

3.2 Apparatus

3.2.1 Optics Bench

The FIR Optics Bench is a structural interface, 1193.8 mm x 895.4 mm x 107.9 mm, that will provide a surface for mounting diagnostics packages and other experiment equipment. The bench has T-slots laid out in a grid pattern on 50 mm centers. This grid will be used for placing the experiment diagnostics and moving them to the ending position. There is also an array of detents on 12.5 mm centers for precise positioning of components. These detents along with the alphanumeric labeling system have been used to simplify the setup and reconfiguration of the experiments, and also to aid in precise positioning of the diagnostics.

3.2.2 Experiment Equipment

The apparatus used for the FIR Optics Bench Experiment included three life-sized drawings of the Optics Bench. These drawings were mounted to a magnetic surface on which the 2-dimensional diagnostic representations, which used actual dimensions, made out of foam board, could then be mounted by the

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use of magnets. A black dot was placed on each diagnostic representation to provide a point of reference for orientation. Each of the three Optics Bench drawings had different labeling devices and participants were either given just written directions or written directions plus a map. The combinations used are shown in the following table.

Table 1 Experimental Optics Bench Design Differences

Experiment A	Gridlines Labeled	Yellow Gridlines	Map & Directions
Experiment B	Blocks Labeled	Yellow Gridlines	Map & Directions
Experiment C	Blocks Labeled	N/A	Map & Directions
Experiment D	Blocks Labeled	N/A	Directions

In Experiment A, the grid lines, which represent the T-slots, were labeled and there were also yellow high-lightings in some of the grid lines, which were added to provide additional reference points for the participants. In Experiment B, the blocks, which are the surfaces between the T-grooves, were labeled and there were also yellow high-lightings in some of the grid lines. Experiments C and D shared the current Optics Bench design where the blocks were labeled, but there were not any additional high-lightings. Each experiment involved a different setup of the diagnostics on the Optics Bench, to prevent any carryover effects. For Experiment A, B, and C the participant was provided with both written directions and a map showing the layout of the experiment setup, whereas for Experiment D, the participant was only provided with written directions. Figure 1 shows the apparatus with the layout for C and D on the left, B in the middle and A on the right. The diagnostic representations are shown mounted on the layout for B. Figure 2 shows a closer view of the layout for B. All directions, maps, and paperwork used to conduct this study can be found in Appendix A.

3.2.3 Procedure

Each participant was brought into the room and asked to pick a number out of an envelope. Each number was assigned to one of the counterbalancing sequences. The number was then disposed of and the sequence was written down. The participant was asked to be seated and informed that a standard set of directions would be read to them and for them to please bear with the experimenter as she read the standard directions. The standard directions (Appendix A, A.2) were then read, during which the participant was asked to sign a consent form (Appendix A, A.3) and two standard examples were shown to explain the tasks of placing the diagnostics on the Optics Bench. After the standard examples were shown the participant was asked if he/she had any questions. Any questions asked were then answered at this point. Once the questions were answered, the participant was then given the first experiment, which he/she would complete.

The participant would then say when to start and when to stop the clock depending on when one was ready to start and when they believed they were done with the task. During each experiment the experimenter/evaluator would record any items of interest or concern, as well as the methodology, which each participant seemed to be using to complete one's task. After each experiment the experimenter/evaluator would stop the clock, record the time and check the accuracy of the black dot on the diagnostic and how lined up with the correct ending position. If any of the diagnostics were not correctly aligned the experimenter would show the participant the correct placement and continue checking. Once the experiment was thoroughly checked the participant was informed "good job" and the diagnostics were removed from the Optics Bench and placed on the Diagnostics table.

This same process was then completed for the other three experiments. When the participant finished all four of the experiments he/she was asked to complete the Questionnaire (Appendix A, A.8), while the experimenter reconfigured the experiment apparatus for the next participant. After completing the questionnaire the participant was thanked for his/her participation and help and any questions or

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comments that he/she had were discussed. Quite a bit of useful information was often gained in this discussion time.



Figure 1 Basic Experiment Set-up

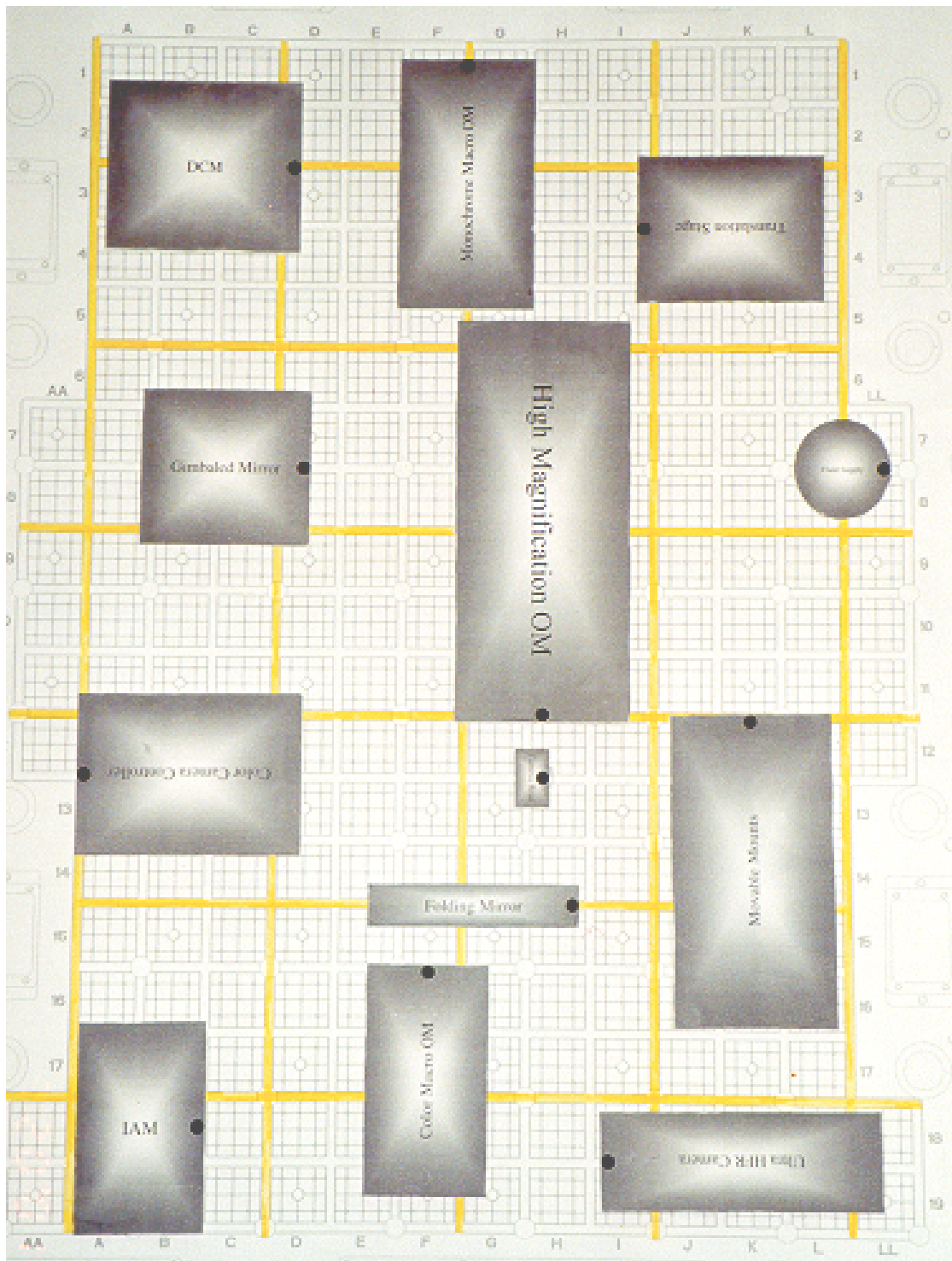


Figure 2 Optics Bench "B" with the diagnostics aligned

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4.0 ANALYSIS AND RESULTS

The data collected in the FIR Optics Bench experiment and analyzed in a variety of different ways. The main measurements taken were of the time and accuracy of the placement of the diagnostics, on the Optics Bench, by each participant for the four different experiment trials. Additional information was also gained in a questionnaire, which each participant completed after he/she had finished all four experiments.

4.1 Data Analysis

The data collected in this experiment was all entered into an Excel worksheet, and analyzed in a variety of different ways. The data was also analyzed using a statistical package called HMSTAT to determine if there was a statistical significance between any of the data collected. In all of the analyses the times of each participant were taken along with the number of errors from that participant and were integrated. For each error made per trial, 15 seconds were added on to that individual's time. An assessment has not been made of the sensitivity of this error time factor.

4.1.1 Times vs. Design for Each Trial

For this analysis this total time, with the errors added in, were graphed for each of the experiment set up and the four trials, which were made with that experiment. See Figure 3.

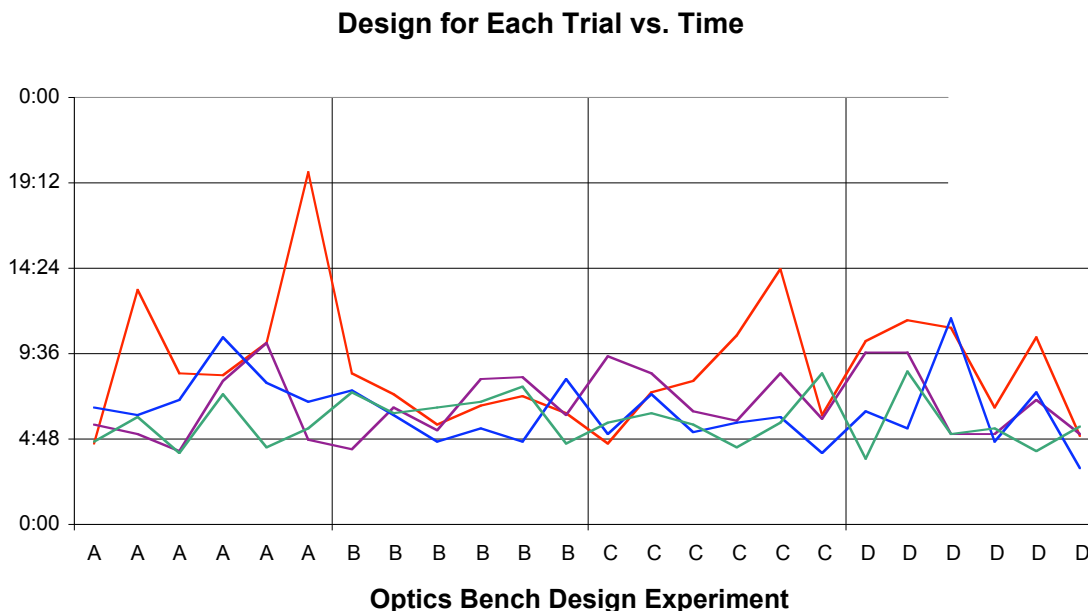


FIGURE 3 Graphical Analysis of Each Experiment Setup vs. Time

Figure 3 shows an excellent graphical representation of all of the data collected in FIR Optics Bench Experiment. The graph shows the data collected for each of the experiment setups - A, B, C, and D and has it additionally broken down by each of the trials, or the order in which the experiment was performed. Graphically it appears that Experiment B tends to have an overall lower average time for all of the Trials. The Optics Bench design used in Experiment B is the grid design layout where the Blocks are labeled and the additional yellow high-lightings in the gridlines. It also appears that Trial 1 which is the data for all of the participants' first trials tend to have higher average times and these averages progressively get lower with each additional trial.

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4.1.2 HMSTAT Analysis

The statistical package HMSTAT was used to conduct a variety of different Analysis of Variance (ANOVA) assessments, which look at the statistical differences between the independent variables. The independent variables for the FIR Optics Bench experiment are identified as: the labeling of the Blocks vs. Grid Lines, the Use of Yellow high-lighting vs. W/out Yellow highlighting, and the used of Directions vs. Map and Directions. For the data collected in the FIR Optics Bench Experiment, the data needed to be analyzed using a Repeated Measures ANOVA. However, a One-Way ANOVA can be used to represent the Repeated-Measures ANOVA by modifying the terminology used in the One-Way ANOVA. This is done because in a One-way ANOVA you can have multiple groups with one condition, and in the Repeated Measure ANOVA you have one group that is exposed to multiple conditions. The following Chart shows how the terminology is modified.

TABLE 2 How One-Way ANOVA is modified for Repeated-Measures ANOVA

ONE-WAY ANOVA	REPEATED-MEASURES ANOVA
Between-groups Sum of Squares	Between Conditions or Between Sum of Squares
Within-groups Sum of Squares	Split into two terms (Subjects and Errors)

All data shown in this report is labeled as One-Way ANOVA, but actually represents this modified terminology.

4.1.2.1 Experiments A, B, C, and D

To determine if there was any statistical significance between the different experiments a modified One-Way ANOVA was used. All of the times, with the errors already factored in, for each of the participants was entered into the HMSTAT, the following diagram is representation of the information and following that is a description of the results.

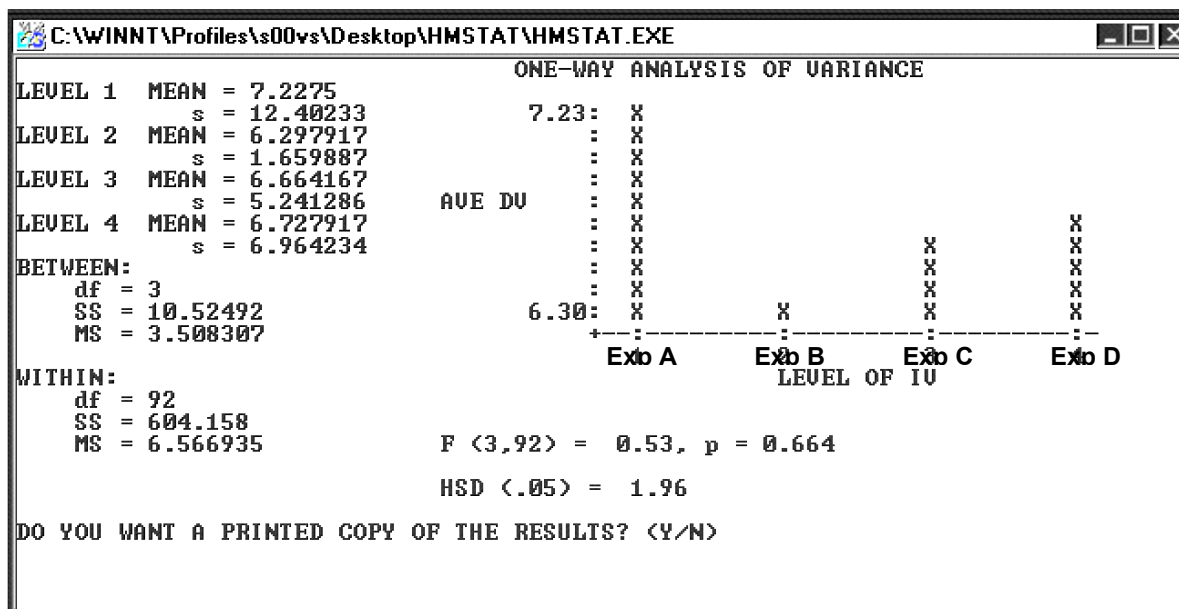


FIGURE 4 HMSTAT – Modified One-Way ANOVA for all data points for Experiments A, B, C, and D, which look at the statistical difference between all four experiment set-ups.

RESULTS:

MEANS AND OVERALL F:

The means for Experiment A, B, C, and D were 7.23 min., 6.30 min., 6.66 min., and 6.73 min respectively. The means do not differ significantly between the times for Level 1 (Exp A), Level 2 (Exp B), Level 3 (Exp C), or Level 4 (Exp D) using a modified One-Way Within-Subjects Analysis of Variance (ANOVA), $F(3,92) = 0.53$, $p = 0.664$. Thus the different experiment designs do not appear to have significant effect on the times of the participants.

LOOKS LIKE:

From looking at the graphed means it looks like the participant times on Experiment B had a considerably faster average time than any of the other Experiment Designs.

DISCUSSION:

The results from this statistical analysis although there is no significant difference between the four different experiments, appear to show that Experiment B has a visibly faster average from the other designs, showing that it might indeed be the best optics bench design. Although looking at the total amount of errors for the four experiments shows that Experiment B happens to have the highest number errors. The errors for each of the experiments were A (17), B (18), C (17) and D (15) although not statistically significant it is a factor that must be considered.

4.1.2.2 Blocks vs. Grid lines

To determine if there was a significant difference between the Blocks vs. Grid Lines the data (with errors added in) of the six participants that had A and B before C or D, was entered into HMSTAT under the One-way ANOVA category. The following diagram is the information, which was calculated by the HMSTAT program.

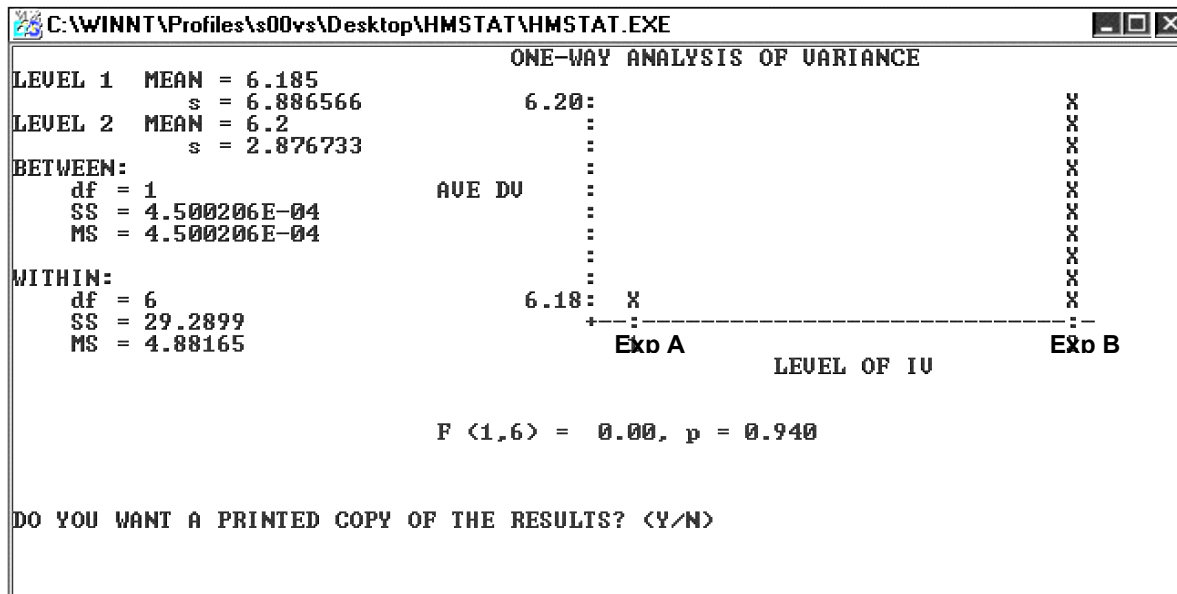


FIGURE 5 HMSTAT – Modified One-Way ANOVA for the first six data points for Experiments A & B, which looks at the statistical difference between the labeling of Blocks and Grid lines.

RESULTS:

MEANS AND OVERALL F:

The mean amount of time it took each participant to complete Experiment A's set up was 6.185 min, and the participant time to complete Experiment B was 6.2 min respectively. The means do not differ significantly between the times for Level 1 (Exp A) and Level 2 (Exp B), using a modified One-Way Within-Subjects Analysis of Variance (ANOVA), $F(1,6) = 0.00$, $p = 0.940$. Thus the different labeling of the grid designs do not appear to have a significant influence on the time.

LOOKS LIKE:

From looking at the graphed means it looks like the participant times on Experiment A had an overall faster average of time than the participant times on Experiment B.

DISCUSSION:

These results are a compilation of six participants who performed Experiment A and B before C and D. The data from the other 18 participants was not used in this analysis due to the belief that performing Experiments C and D might have skewed the results. When an analysis was conducted using all of the data points for Experiments A and B, although there was still no statistical significance in the data, Experiment B appeared to have a faster average of time over Experiment A. This is believed to be due to carryover effects from Experiments C and D, since these experiment grid designs are the same layout as B, and would have preceded the participant's interaction with B.

4.1.2.4 Directions vs. Map & Directions

Experiment C and D were compared to determine if there was any statistically significant difference in times (with errors added in). These two experiments were compared due to the fact that they both had the same Optics Bench design and the only differences between the two experiments were the different diagnostic layouts, and the used of just directions (Exp D) or map and directions (Exp C).

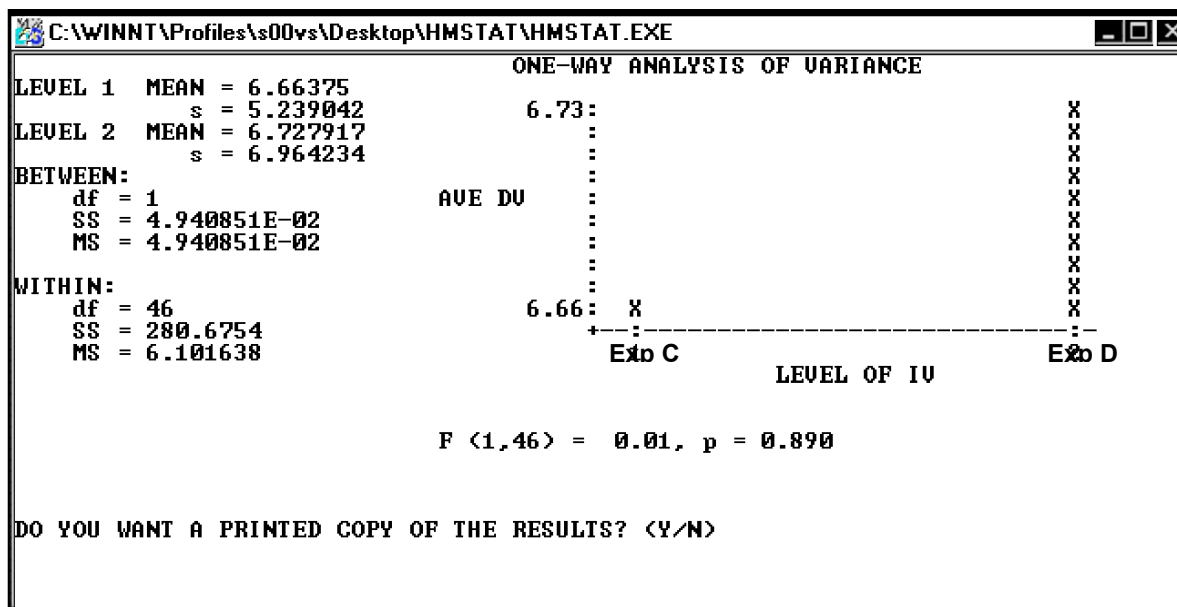


FIGURE 7. HMSTAT – Modified One-Way ANOVA for all data points for Experiments C & D, which looks at the statistical difference between using just Map and Directions or just Directions.

RESULTS:

MEANS AND OVERALL F:

The mean amount of time for Level 1, Map and Directions was 6.66 min, and Level 2, Directions was 6.73 respectively. The means do not differ significantly between Experiments C and D, using a One-Way Within-Subjects Analysis of Variance (ANOVA), $F(31,46) = 0.01$, $p = .890$. Thus there does not appear to be any significant effect on the times if just directions or a map and directions were used.

LOOKS LIKE:

From looking at the graphed means it appears that the mean time for Experiment C is considerably less than the mean of Experiment D, thus showing to some degree that the Map and Directions seemed to have a lower mean, or faster times.

DISCUSSION:

Although the mean times were faster for the participants with the Map and Directions it seems that often times, some of the participants might not have used the two methods to cross check their work,. This is stated because the number of errors, although not statistically significant for Experiment D, was less than the number of errors for Experiment C. This is an important consideration, because not only is time an important factor, but so is accuracy.

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4.2 Questionnaire Results

The following is a compilation of the data, which was collected from each participant's questionnaire. Participant's comments are shown in italics. Following each comment are four letters that represent the order of the experiments performed by that participant.

4.2.1 Grid Lines vs. Blocks

The following statements are a compilation of the participants "Explanation of one's preferences." A total of 54% of the participants preferred the Optics Bench layout method with the Grid lines labeled, instead of the Blocks being labeled, whereas a total of 46% of the participants, which participated in this experiment, preferred the Block Labeling method to the Grid Line method.

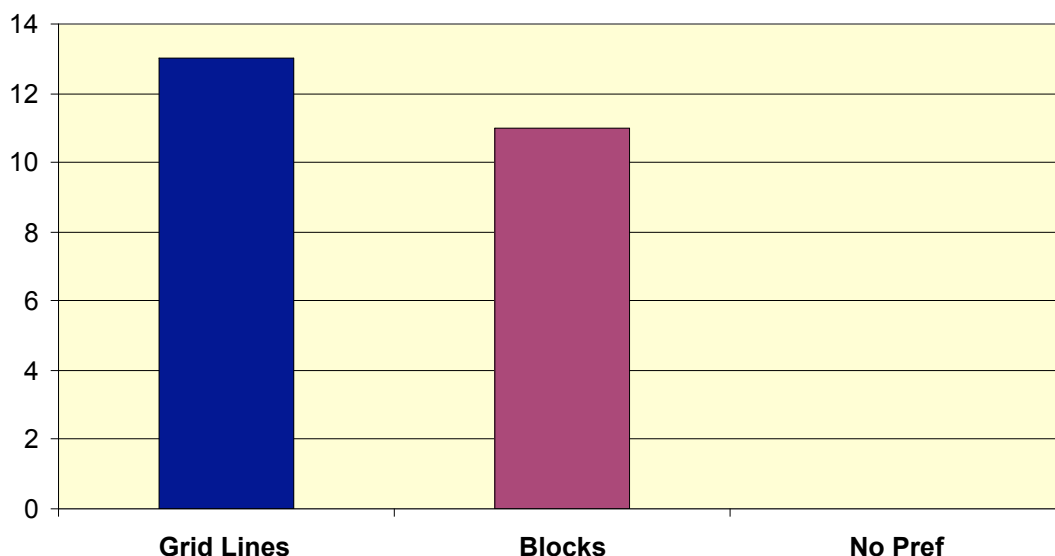


Figure 9 Participant's Preferences: Gridlines vs. Blocks

4.2.1.1 Gridlines Labeled – 54%

This labeling format appeared to be favored due to participants experience with universal maps and grid labeling. The participants' preference might show a bias of what they thought would be the easiest, even though this questionnaire was completed at the end of their participation in the experiment.

Comments:

"...It was easier looking for "single letter" columns than looking for intersections." ABCD

"Single letters to remember rather than two." BDAC

"Similar to Universal X-Y coordinate mapping." ACDB

"Blocks are more confusing than lines." BCDA

"Easier to follow and more intuitive...like a regular map." CADB

"Labeled grids made it easier to identify the starting block." BDCA

"ABC Grid lines w/ yellow allows fast visual orientation of blocks." DABC

"The lines being labeled is more logical and is in line with a coordinate system...like I'm used to." DACB

"...had fewer letters to look for." DBCA

4.2.1.2 Blocks Labeled –46%

This method of labeling was favored by a little less than half of the participants. It is hypothesized that the participants' preference might be skewed due to the fact that there were three times as many examples of this layout over the Gridline layout. A participant might have become more comfortable completing the task on the Block Labeled Optics Bench, because he/she had more experience with it.

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Comments:

"...easier to verify ending (target) location...in relation to the detents, because you knew exactly which block you were supposed to be on." **CBDA**

"...helped me locate faster because I could find a 'larger' area easier than a point" **BACD**

"...layout technique didn't matter b/c I relied mostly on the map and not the directions. When I had to use the directions, the labeling of the blocks was easier." **CABD**

"...blocks were easiest to use, although not the most direct." **CDBA**

"...blocks made it easier for finding the detent to line up the dot." **BADC**

"with block labeled 'B(1)' it is less ambiguous than when B is between two blocks and you have to figure out which block you are supposed to use." **ABDC**

4.2.2 Additional Labeling: Yellow-W/out Yellow Grids

The following is a compilation of some of the participant's comments on why they preferred the optics bench designs, which had the colored grid lines, which broke the overall optics bench grid into smaller areas. A total of 58% of the participants preferred the optics bench with this additional labeling device, whereas there was a total of 29 % of the participants, which had no preference, and only 13% preferred the optics bench with out any additional gridlines at all.

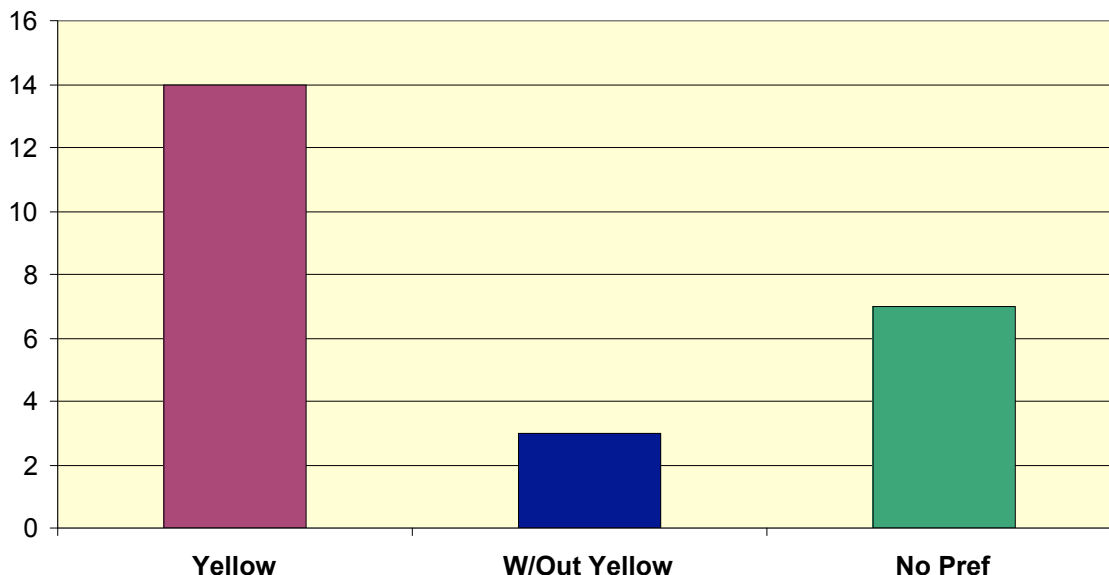


Figure 10 Participant's Preference: Yellow vs. W/out Yellow Gridlines

4.2.2.1 Preferring Yellow grids – 58%

The majority of the participants did indeed prefer the yellow gridlines to not having yellow gridlines. Most participants acknowledged that the additional reference points on the Optics Bench seemed to aid them in the placement of the diagnostics.

Comments

"Yellow Grids allow a better double check against the map." **BDAC**

"Yellow grids made identifying given grid positions easier." **BDCA**

"ABC Grid lines w/ yellow allows fast visual orientation of blocks." **DABC**

"Yellow grids keep the eye from wandering to a neighboring line." **ABDC**

"Yellow lines made the paths clear." **ACBD**

"Yellow gridlines made it easier in the middle of the bench." **DBCA**

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4.2.2.2 W/out Yellow Grid – 13%

A common reason given by the participants for not preferring the yellow gridlines was mostly because they felt that it just made the optics bench more cluttered with labeling devices.

Comments:

"Yellow lines can be confusing." **CDBA**

"The yellow lines just tended to 'clutter' the display." **ABCD**

"Just bolder gridlines, not Yellow." **DBAC**

4.2.2.3 No Preference –29%

Quite a large number of participants had no preference to the yellow lines. It is hypothesized that the yellow lines did in fact add additional reference points even if it was just on a subconscious level and the participant was not aware of how much the yellow gridlines actually did help.

Comments:

"I don't think I used 'yellow grids' at all in my decision making." **BACD**

"Yellow lines made it a little easier, but weren't necessary." **DACB**

4.2.3 Directions vs. Map & Directions

The following is a compilation of some of the participant's comments on why they preferred the having either the Directions or the Map & Directions when completing the tasks of placing the diagnostics on the Optics Bench. A total of 13% of the participants preferred just having the Directions, whereas there was a total of 79 % of the participants, which preferred both the Map & Directions, and a few participants, reaching a total of 8%, wrote in that they preferred just using the Map 13% when placing the diagnostics on the Optics Bench.

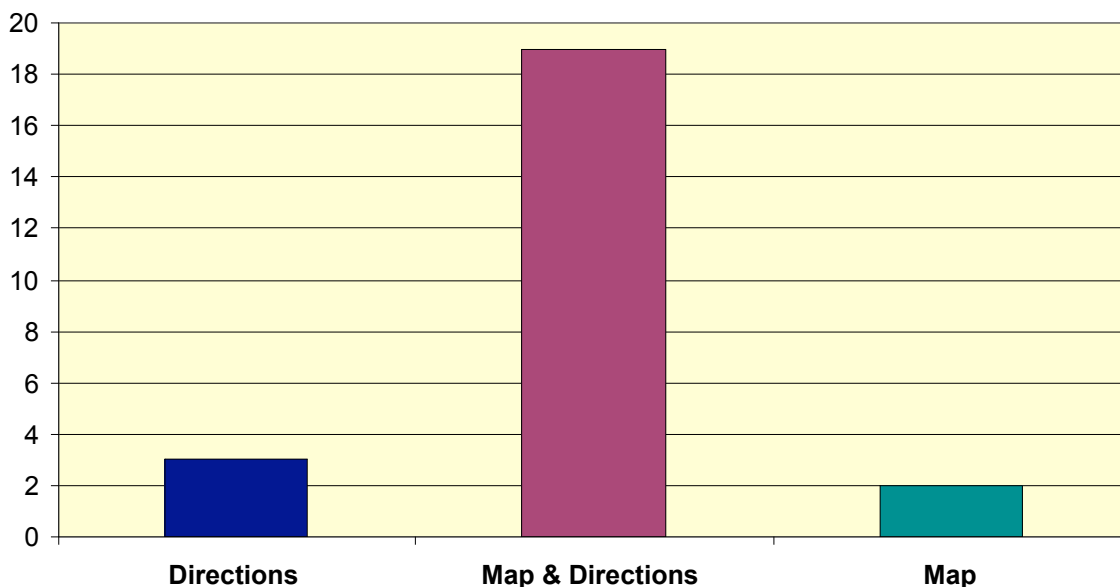


Figure 11 Participant Preference: Directions vs. Map & Directions

4.2.3.1 Directions = 13 %

It appears that the participants which preferred just the directions, because they felt like the map was hard to follow, and the wanted to make sure they were placing it in the exact position. Others seemed to realize that using both the map and directions would most likely take more time to complete the task. Although, when just the directions were used this method appeared to show that less errors were made, than when individuals had a

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map. It is hypothesized that this is a direct effect from the participant's knowledge that he/she could have used the map to cross check themselves in the other examples, whereas when just using the written directions, he/she knew that he/she had to get it right the first time.

Comments:

"Trying to reduce time, didn't use map." DBAC

"Took less time (didn't have to consult both...map made me second guess myself)" ACBD

"The map was hard to follow, I only referred to it if I couldn't follow the directions." DACB

4.2.3.2 Map and Directions = 79%

This method of presenting the information to the participants seem to be the most preferred, because the participants could cross check themselves on their work. A visual reference was also helpful for the individuals.

Comments:

"Both allowed for visual and text to show where to place object." CBDA

"I visualize maps quicker and more accurately...Picture is worth 1000 words." BACD

"Using Map and Directions in combination instills more confidence in the subject but may take more time than using directions only." CADB

"Only used the map as a backup, but I was able to catch a few mistakes I would have missed with only directions." ABCD

"On Earth, both seem fine...but on-orbit how many references can the crew handle?" CDAB

"Nice to have two sources to check against." CDBA

"If I was unsure I could refer to the map." BCAD

"Map allowed a better double check on location (after placed) and orientation (when placing)." BDAC

"Print directions portrait like the map." CBAD

"Map provides method of back check." DABC

"I liked to use the map when I was either confused or wanted to check the orientation of the blocks and when I was finished." BDCA

"Map was useful as a reference for correctness afterwards." DBCA

"The map is very helpful for those people preferring a visual source of directions and it simplifies the process."

DCBA

"I used the directions to place things and the map to double-check." ABDC

"The map is good for a visual double-check." BADC

4.2.3.3 Map = 8%

The map alone was not an option on the questionnaire, but a few participants added in the option of using just the map. If this method were to be used, it would be recommended that the ending position be stated next to the diagnostics reference point, on the map.

Comments:

"It was easier to visually locate the devices on the map than it is to read where they are supposed to go." CABD

"Map ONLY works just fine." ACDB

"Map is Easiest." BCDA

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4.2.4 Recommended Entry Point vs. No Entry Point

The following information was gathered to determine if it was really necessary to have an entry point given in addition to the ending point. It appears that the majority of the participants, 88%, preferred to have the entry point, even after being told that they did not have to use the recommended entry point. Whereas only 12% preferred not to have the entry point, mostly because it was an extra step, and they didn't feel it was necessary.

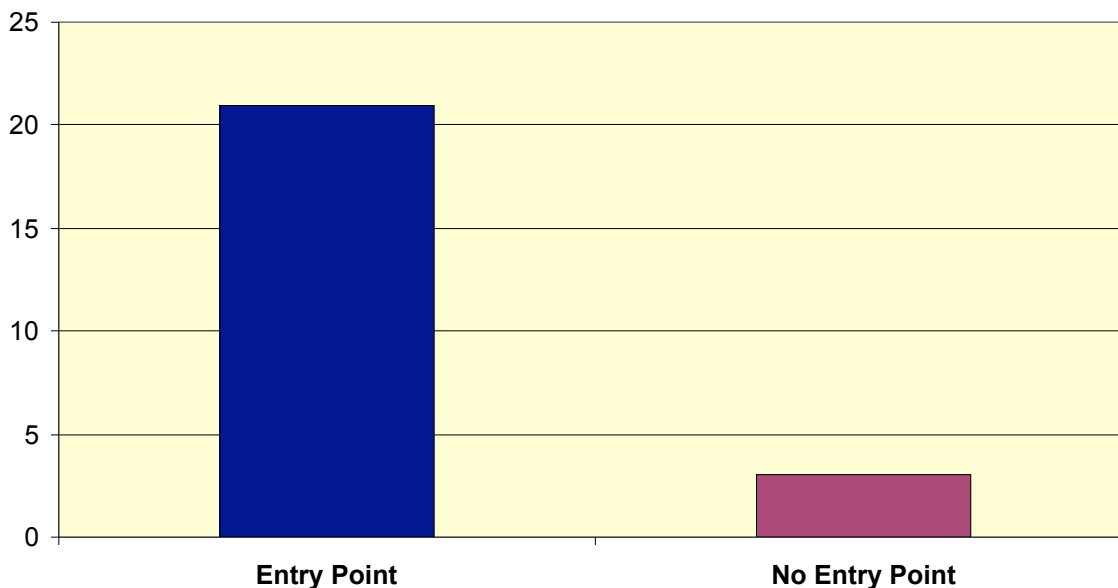


Figure 12 Participant Preference: Recommended Entry Point

4.2.4.1 Entry Point = 88%

The recommended entry point often times added an additional cross check point for the participants; a number of times the participants ended up catching a mistake which was made with the placement of a previous diagnostic, when he/she was trying to put a surrounding diagnostic into its entry point, and it wouldn't fit, because the other diagnostic was over a couple of detents or down an extra gridline, etc.

Comments:

"Entry point was usually the closest to the ending position." **CBDA**

"Closer is better." **DBAC**

"Doesn't matter in the beginning of the exercise; more as the optics bench gets crowded it would help." **CDAB**

"Minimizes the movement." **BACD**

"With the recommended entry points it seemed a lot easier." **CABD**

"Makes Sense!" **CDBA**

"It gave me a place to start so I didn't have to think about starting." **BCAD**

"It takes the 'decision making' out of that part of the task." **ABCD**

"It was a definite starting point, I would spend time trying to decide where to enter if not given them." **ACBD**

"Otherwise you could put it anywhere and then may have to move it a lot further or other objects may get in the way." **DACB**

"Allows quick application to grid, then fine tune by sliding." **DABC**

"Identified the area of concentration." **BDCA**

"It was easier when given written directions to have one, but not necessarily needed if given only a map." **ADBC**

"It was better to start at a clear location for locations in middle." **DBCA**

"Used recommended entry point randomly...often used own judgment." **CADB**

"It will get to the end point with the shortest distance." **ACDB**

"You would need to enter without interfering with another piece." **ADCB**

"Although not needed initially, entry position helps once bench is half populated." **DCAB**

"It simplified the task." **BADC**

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4.2.4.2 No Entry Point – 12%

A few participants preferred not having the extra entry point, because it was an added step that had to be taken, and they preferred just finding the ending position and then finding a entry position near that point.

Comments:

"It took me an extra step to find it and then the final location. I might have used different entry points if not specified." **BDAC**

"Didn't care!" **BCDA**

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5.0 CONCLUSIONS

After a through analysis of the data collected from the FIR Optics Bench Experiment, some preliminary conclusions have been made. These conclusions are based off of the information that was gathered and analyzed from each experiment. Although since no significant statistical differences were found in the data, except that each participants time increase after each trial, it is recommended that the experiment be conducted again to check the validity of the results found from the graphical representations of the data.

Although it was hypothesized that the Gridlines would provide a better method of presenting the alphanumeric labeling system, no statistically significant observations were made by the use of the One-Way ANOVA. However, when the means of Experiments A and B were compared, without any of the other Experiments having an effect on the results, Experiment A did in fact have a lower mean and a lower number of errors made than Experiment B. One would then hypothesize from this analysis of the data gained, that Experiment A was a more efficient and accurate way of presenting the alphanumeric labeling system.

Another labeling system researched was the used of the yellow gridlines; it was hoped that these gridlines would add an additional visual cue for the crewmembers use when applying the diagnostics. Again, it is important to keep in mind that although there was no statistical significance found when using the modified One-Way ANOVA, it did appear that the use of the additional highlighting of the gridlines did aide the participant in applying the diagnostics. Thus it would be recommended that the additional highlighting of the gridlines be added to the current design of the Optics Bench. The yellow would obviously not be the recommended color, it was just used for this experiment, but some form (a darker coating, etc) of distinguishing a visual difference would be recommended.

In regards to the method in which the information regarding experiment set-up is relayed to the crewmembers, it is recommended that both a map and directions or some format in which the two methods are combined be used. It was observed that the map and directions not only were preferred by the participants in this experiment, but that the overall time/accuracy of their results appeared to be better than when just the use of directions. It is from this data and analysis that the recommendation is made to ensure the used of both a map and directions. Another recommendation would be to design these procedures so that the crewmember cannot miss a step by accidentally overlooking it. This might be achieved by using a system in which only one step is shown at a time, and once the step is completed the screen flows thru to the next step. This recommendation is made from the observation that a few participants ended up missing the application of a diagnostic to the optics bench, and didn't catch this mistake until the end when they had an extra diagnostic laying around and had to figure out where it went. This didn't cause any complications with the FIR Optics Bench experiment, but might cause some serious problems, or concerns if it occurred in real time.

The final item analyzed deals with the recommended entry point. This procedural task was only researched by means of observation and the questionnaire, which provided the participants preference. The recommended entry point should provide the crewmember with the entry point not only closest to the ending position, but also an entry point which provides the easiest, most straightforward method of translating the diagnostic to its ending position. In providing the entry point, this lessens the mental workload of the crewmember in applying the diagnostics.

In conclusion, although there was not statistical significance found for any of the independent variables analyzed, valuable information was gathered thru observation and the analysis of the independent variables. It is hypothesized that the design of the experiment, affected the fact that no statistical significance was found between the independent variable and the dependent variable. This hypothesis is generated by the concern that the design was too complex, and that the independent variable should have been tested individually. It appears that although precautions were taken to prevent any confounding variables and carryover effects, that not enough precautions were implemented.

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5.1 Comparison to success criteria

If the experiment were to be conducted again, which is highly recommended, that the independent variables be separated. For example, run an experiment in which the participants just complete Experiments A and B, without the yellow gridlines, so that just the alphanumeric labeling system is being analyzed. To study the yellow gridlines, use optics bench designs with the same alphanumeric labeling system, and do the same for analyzing the use of directions or map and directions. This could be done by using either a between subjects design or even a within-subjects design, by spreading out the exposure to each condition. In conducting the experiment again it is hypothesized that the conclusions made in this report will then become statistically significant.

5.2 Experiment Recommendations:

It is recommended that the FIR Optics Bench Experiment be conducted again to further test the validity of the results and conclusions where were made. In conducting the experiment again, it is suggested that the number of independent variables be broken down to just two; with those two being the yellow highlighted lines and the other being the Block and/or Grid lines being labeled. This will provide a more focused look at the difference between the labeling techniques and should provide more solid data.

5.3 Procedural Recommendations noted by the Observer

- Provide plenty of references for directions and labeling of detents. The detents seemed to cause a lot of confusion)
- Keep in mind that often times a participant's background tends to affect one's thought processes
- If using a recommended entry point it is recommended that it is above the ending position and/or in an area so that the movement required to get to the ending point doesn't cover up the ending point or block the view before getting to that position.
- Have entry point closest to the ending point
- Make sure that all numbers and letters can be distinguished between in any and all written directions and labeling, specifically the letter I and the number 1.
- Be sure that ALL labeling (i.e. Terminology, visual appearance/format) on diagnostics matches labeling on written directions, maps, and any other tools or documentation provided to aid in populating the bench.
- Have directions pop-up one at a time on the laptop in a way that a step doesn't get skipped on a list. i.e. have the screen change as step changes.
- Be sure maps show TRUE representation of the actual appearance once on the Optics Bench
- Relay information on the order, that the diagnostics should be moved so that they do not get stuck trying to move it in one direction and then realize they should have moved it in the other direction first.
- Get rid of AA and LL and just use single letters, this letter format tended to cause more confusion.
- Be specific as to what areas on the diagnostics are supposed to match up with what areas on the Optics Bench.

6.0 NOTES

A compilation of things noticed during observation of the participant completing the task.

- Mistakes were often caught when another diagnostic wouldn't fit into its recommended entry position.
- Times on D...might have been faster because the participants didn't have the map to cross check with
- Preference to a specific layout might have depended on what format the participant started with.

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- Similarly, ABC Blocks might have been preferred because there were three trials with this design and only one trial of the ABC Grid lines.
- Times on experiment A might have been considerably slower if it were given as trial 3 or 4 because the previous 2 or 3 trials had been used with the ABC Block method, and the participant had to change one's train of thought.
- Detents seemed to cause a LOT of confusion. Be sure to explain the methodology behind the way it should be used thoroughly.
- A participant's height played a key part in how accurate the diagnostics aligned with the ending position. This could possibly mean that even more time will be required in completing the task of aligning the diagnostics accurately by the crewmembers, due to the need to re-adjust restraints to provide oneself with a better visual angle.
- The labeling at the bottom of the Optics Bench was often over-looked and not referenced, whereas the labeling on both the left and right of the optics bench were both used regularly. It is advised that this additional labeling device be pointed out to the crew.

APPENDIX A - APPARATUS

This a compilation of all of the different materials used to conduct the FIR Optics Bench Experiment.

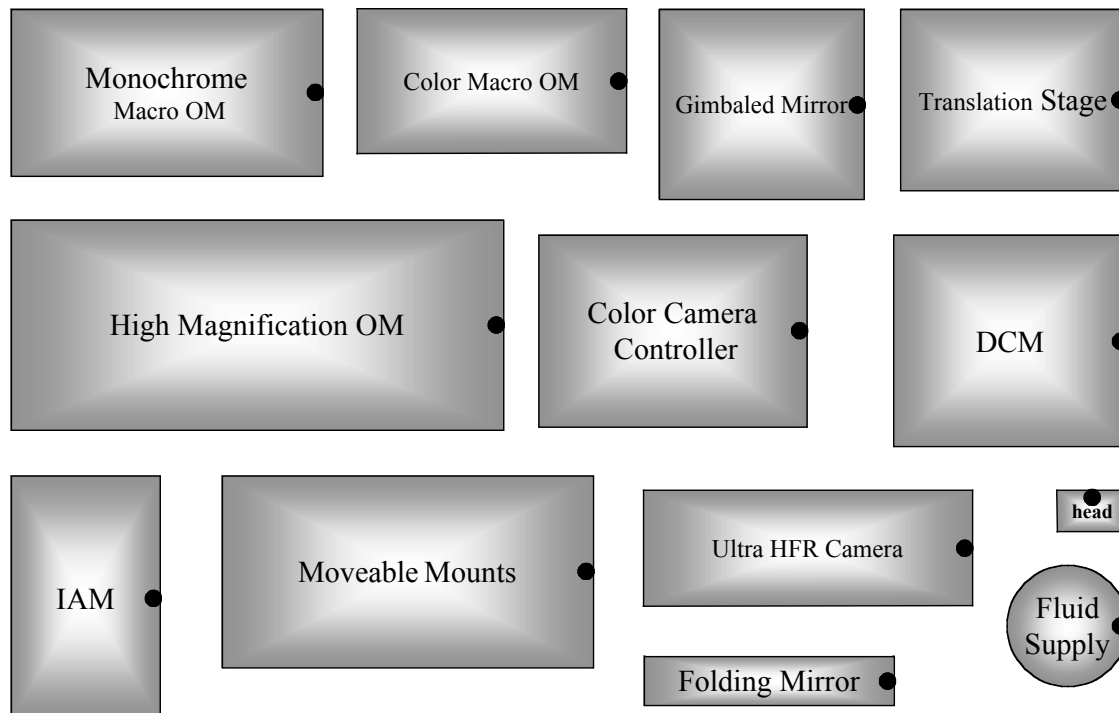
A.1 Diagnostic Representation

Section A.1.1 shows the dimensions of the 2-D diagnostic representations used for this experiment. Section A.1.2 shows the orientation of each dot on the representations.

A.1.1 Dimensions

Camera Head	1.06" x 1.81"	High Magnification OM	5.45" x 12.72"
Color Camera Controller	5" x 6.94"	IAM	6.34" x 3.86"
Color Macro OM	3.74" x 6.97"	Monochrome Macro OM	4.33" x 8.07"
DCM	5.5" x 6.09"	Moveable Mounts	5" x 9.61"
Fluid Supply	3" diameter	Translation Stage	4.72" x 5.91"
Folding Mirror	1.33" x 6.5"	Ultra HFR Camera	2.99" x 8.5"
Gimbaled Mirror	4.96" x 5.31"		

A.1.2 Representations



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A.2 Standard Directions

Standard Directions:

1. Welcome to the Fluids Optics Bench Experiment.
2. Please listen carefully as I explain the directions to you, and what is expected of you as you have volunteered for this experiment.
3. If you would please begin by reading and signing the consent form.
4. Ok. Thank-you....Now lets begin:
5. You will be asked to complete 4 different experiment set-ups. During each of which you will take the diagnostics and place them on the optics bench. (point to each) They will be attached by the use of magnets. You will be timed and the accuracy of your results will be recorded.
6. Please look at the optics bench. (Point to it)
7. There are 3 different optics bench designs, which will be used. All of which have different labeling devices, but have the same grid design. Please notice the larger holes at the intersections of the grid lines. These larger holes will be used as Entry Points for the Diagnostics.
8. Now if you would please take a look at the diagnostics (i.e. – Fluid supply, Gimbaled Mirror) – point to them. Please notice the Black dot on each of the diagnostics.
9. This black dot shall be used as the reference point, which you refer to for your Entry Position and the Ending Position
10. When placing the diagnostic on the optics bench (via magnets) The black dot must match up with one of the larger holes on the optics bench, thus representing the entry point at which real diagnostics must be entered.
11. Once the diagnostic's black dot is aligned with the larger hole, the diagnostic can then be moved to its Ending Position by sliding its way via the grid lines. The Black dot must stay within the grid lines...and will be orientated in a final position in relation to the optics bench, at either 0,90, 180, or 270 degrees, these positions have also been labeled as Top, Bottom, Left, and Right to help aid if the degree positions are not understood
12. Please pay attention as I demonstrate.
13. This information will be given either in the form of a map and/or written directions.
14. Thank-you...Are there any questions?
15. Let's Begin!

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A.3 Consent Form

Human Factors Research Design

Fluids Optics Bench Layout – Participant Consent Form

Date: _____

When I sign this statement, I am giving my informed consent to the following basic considerations:

I understand clearly the procedures to be done; including any that might be experimental. This experiment is based solely on and will be determined using the optics bench mock-up and diagnostics which have been designed by Vicki Smith. I will be asked to arrange the diagnostics on the optics bench by either using written directions and/or a map, which is provided. Following the completion of the arrangement of the diagnostics, the experimenter will record how accurate my results are, and the time in which it took to complete the task.

I understand any discomforts and/or risks that might be associated with this research project. I understand clearly any benefits anticipated from this research project. I understand that provisions have been made to protect my privacy and to maintain the confidentiality of data acquired through this research project.

The experimenter, Vicki Smith, has offered to answer my questions about procedures. She can be contacted for further information about this research project at (216) 433-2044 or via e-mail at Vicki.Smith@grc.nasa.gov. The experiment will be done by the intern, Vicki, under the direction of her mentor, Dennis Rohn, who can also be reached at (216) 433-2044 or via e-mail at Dennis.W.Rohn@grc.nasa.gov.

I understand clearly that I may withdraw at any time from this research project without penalty or loss of benefits to which I am otherwise entitled. I, the person signing below, understand the above explanation. On this basis, I consent to participate voluntarily in the Fluids Optics Bench Layout Experiment.

Signature of person giving consent

Printed name of person giving consent

Signature of principle investigator

Printed name of principle investigator

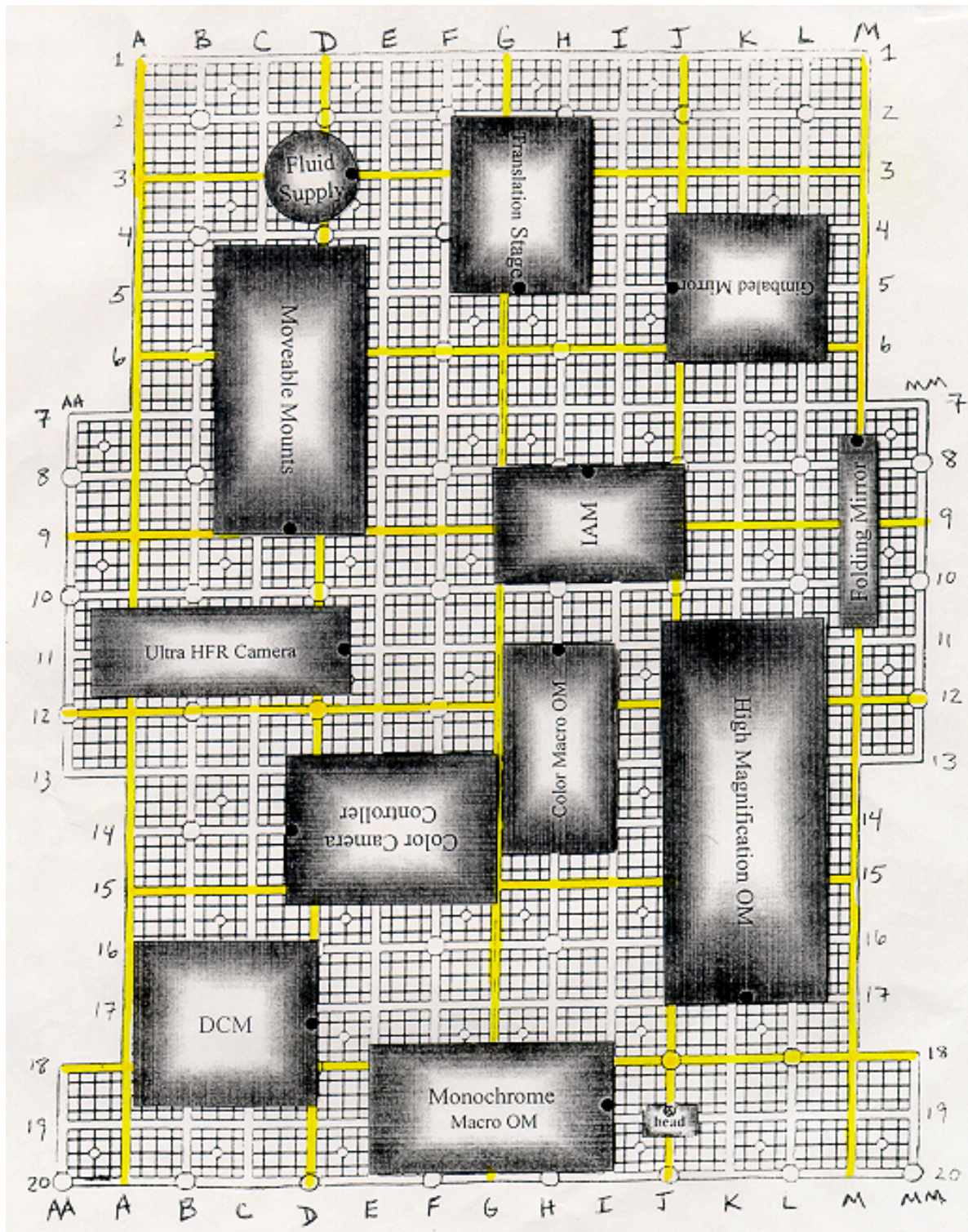
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A.4 Experiment A

A.4.1 Written Directions

TEST	Order	Diagnostic	Orientation of Dot	Recommended Entry	Ending Position	
Exp A				(Column, Row)	Column (Detent)	Row (Detent)
	1	Gimbaled Mirror	270 - Left	(J,4)	I(3)	5(0)
	2	Translation Stage	180 - Bottom	(F,4)	G(1)	5(0)
	3	Fluid Supply	90 - Right	(D,2)	D(2)	3(0)
	4	Moveable Mounts	180 - Bottom	(D,10)	C(2)	9(0)
	5	IAM	0 - Top	(H,8)	H(2)	8(0)
	6	Folding Mirror	0 - Top	(L,8)	M(0)	7(2)
	7	Ultra HFR Camera	90 - Right	(D,10)	D(2)	11(0)
	8	High Magnification OM	180 - Bottom	(J,18)	K(1)	17(0)
	9	Color Macro OM	0 - Top	(H,12)	H(0)	11(0)
	10	Color Camera Controller	270 - Left	(B,14)	C(2)	14(0)
	11	DCM	90 - Right	(D,18)	D(0)	17(1)
	12	Monochrome Macro OM	90 - Right	(H,18)	I(0)	18(3)
	13	Camera Head	0 - Top	(J,18)	J(0)	18(3)
*Yellow filled end on a yellow grid line						

A.4.2 Map- Experiment A



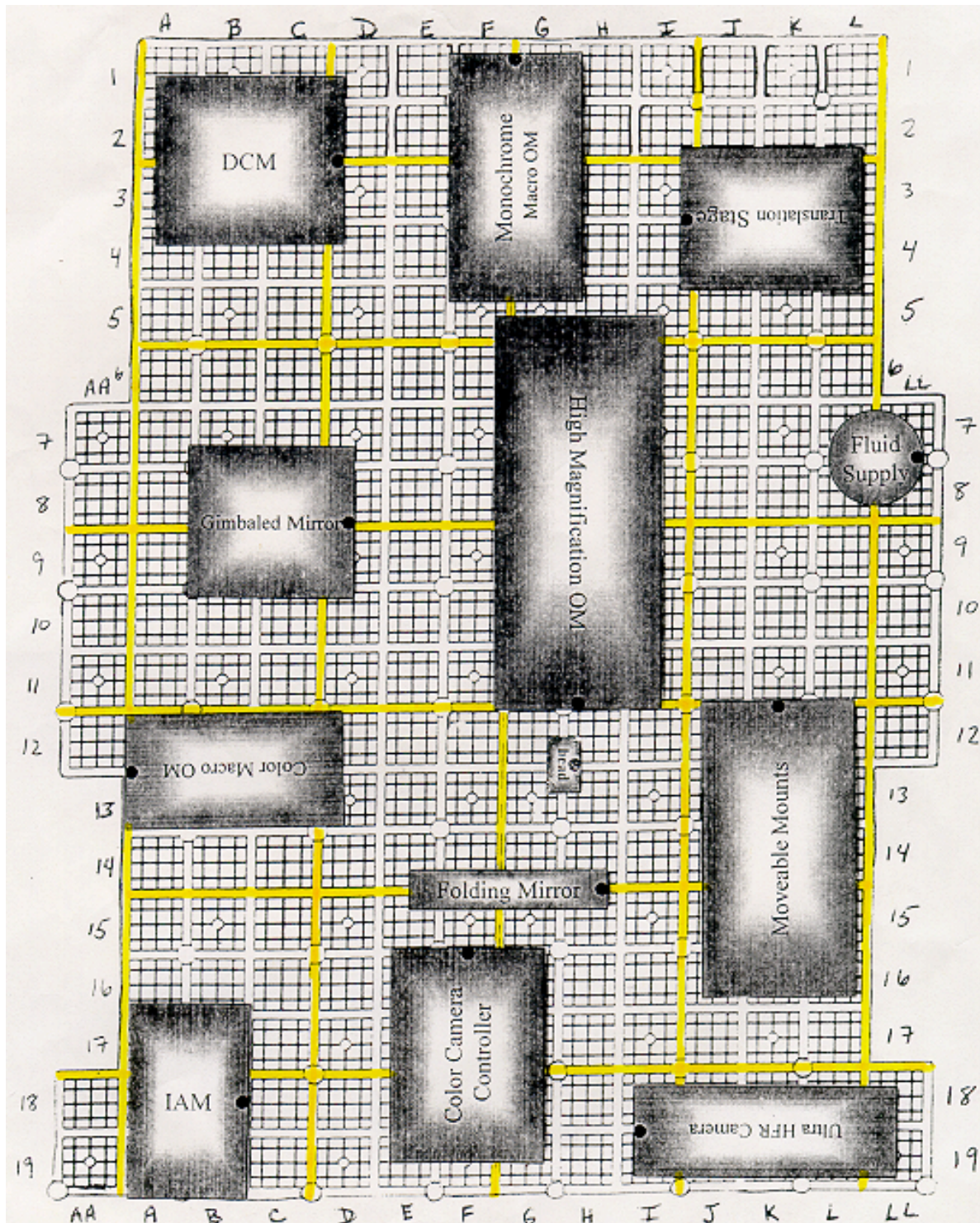
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A.5 Experiment B

A.5.1 Written Directions

Test	Order	Diagnostic	Orientation of Dot	Entry Position	Ending Position	
Exp B				(Column, Row)	Column (Detent)	Row (Detent)
				Between Labeled Blocks	and/or Between Labeled Blocks	
	1	DCM	90 - Right	(C-D, 1-2)	D(1)	2-3
	2	Monochrome Macro OM	0 - Top	(G-H, 1-2)	F-G	1(1)
	3	Translation Stage	270 - Left	(I-J, 3-4)	I(3)	3-4
	4	Fluid Supply	90 - Right	(LL (right of), 7-8)	LL(3)	7-8
	5	High Magnification OM	180 - Bottom	(G-H, 11-12)	H(1)	11-12
	6	Gimbaled Mirror	90 - Right	(C-D, 7-8)	D(2)	8-9
	7	Color Macro OM	270 - Left	((left of) AA, 11-12)	AA-A	12-13
	8	Camera Head	90 - Right	(G-H, 13-14)	H(1)	12-13
	9	Moveable Mounts	0 - Top	(K-L, 11-12)	K(2)	11-12
	10	Folding Mirror	90 - Right	(G-H, 15-16)	H(3)	14-15
	11	IAM	90 - Right	(C-D, 17-18)	B-C	18(2)
	12	Color Camera Controller	0 - Top	(E-F, 15-16)	F(2)	15-16
	13	Ultra HFR Camera	270 - Left	(I-J, 17-18)	I(1)	18-19
					*Yellow filled end on a yellow grid line	

A.5.2 Map- Experiment B



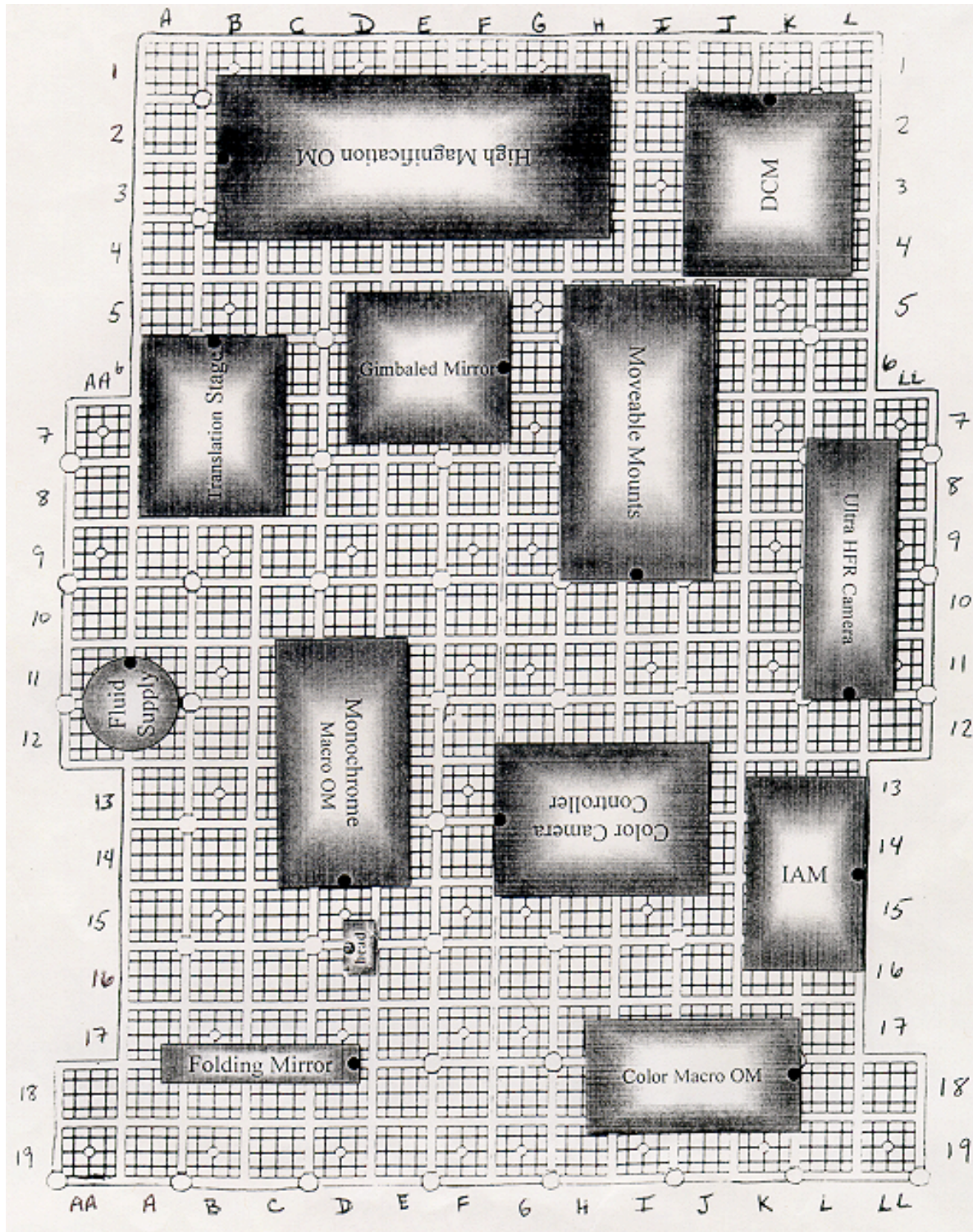
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A.6 Experiment C

A.6.1 Written Directions

Exp C				(Column, Row)	Column (Detent)	Row (Detent)
				Between Labeled Blocks	and/or Between Labeled Blocks (-)	
	1	DCM	0 - Top	(I-J, 1-2)	K(1)	1-2
	2	High Magnification OM	270 - Left	(A-B, 3-4)	B(1)	2-3
	3	Translation Stage	0 - Top	(A-B, 5-6)	B(1)	5-6
	4	Gimbaled Mirror	90 - Right	(G-H, 5-6)	F-G	6(2)
	5	Moveable Mounts	180 - Bottom	(I-J, 11-12)	I(1)	9-10
	6	Ultra HFR Camera	180 - Bottom	(K-L, 11-12)	L(3)	11-12
	7	IAM	90 - Right	(K-L, 15-16)	L-LL	14-15
	8	Color Camera Controller	270 - Left	(G-H, 11-12)	F-G	13-14
	9	Monochrome Macro OM	180 - Bottom	(C-D, 13-14)	D(2)	14-15
	10	Fluid Supply	0 - Top	(A-B, 11-12)	AA-A	11(1)
	11	Camera Head	270 - Left	(C-D, 15-16)	D(2)	15-16
	12	Folding Mirror	90 - Right	(C-D, 17-18)	D(3)	17-18
	13	Color Macro OM	90 - Right	(K-L, 17-18)	K-L	18(1)

A.6.2 Map- Experiment C



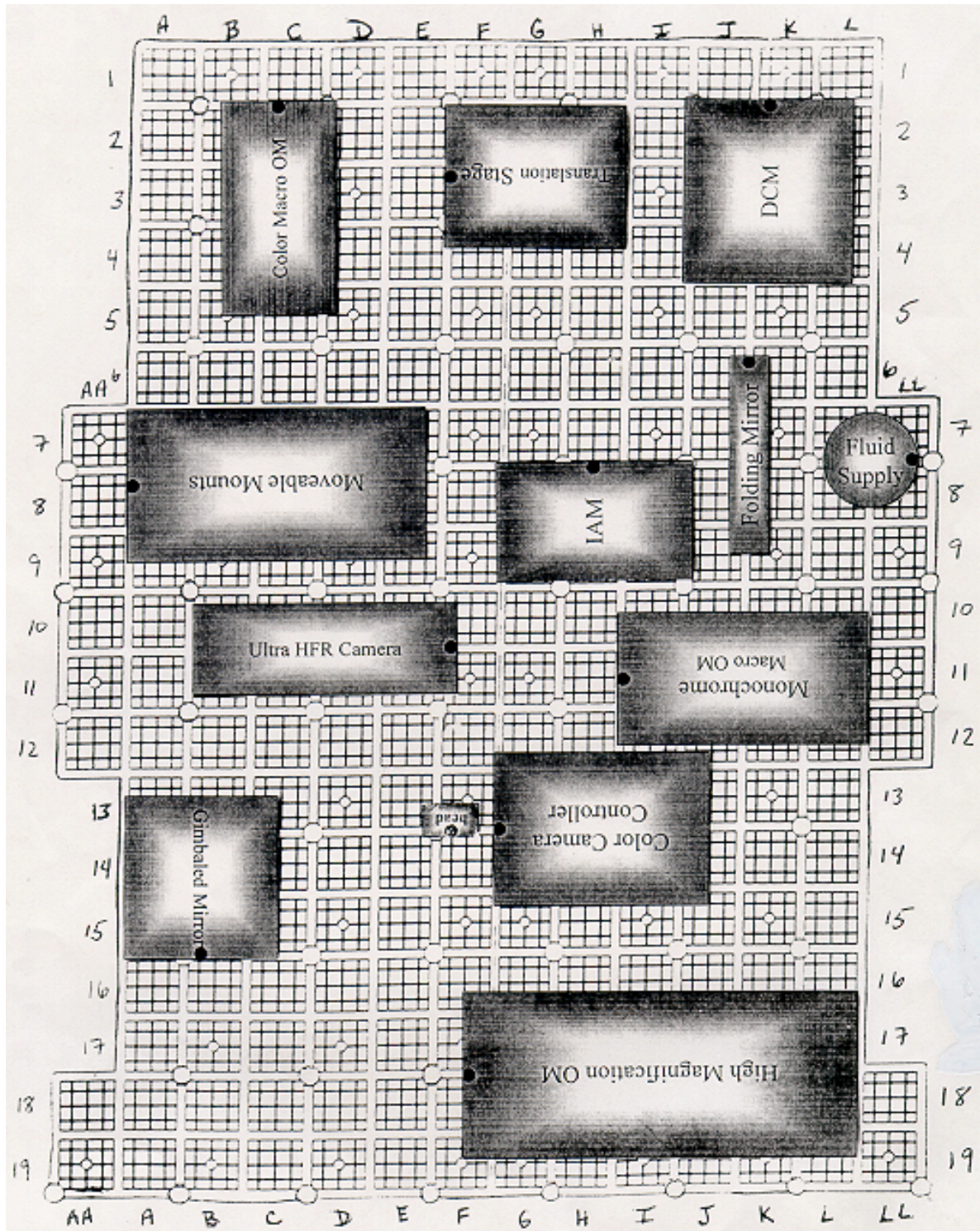
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A.7 Experiment D

A.7.1 Written Directions

Test	Order	Diagnostic	Orientation of Dot	Entry Position	Ending Position	
Exp D				(Column, Row)	Column (Detent)	Row (Detent)
				Between Labeled Blocks	and/or Between Labeled Blocks (-)	
	1	Color Macro OM	0 - Top	(A-B, 1-2)	C(1)	1-2
	2	Translation Stage	270 - Left	(E-F, 3-4)	E-F	3(1)
	3	DCM	0 - Top	(K-L, 1-2)	K(1)	1-2
	4	Fluid Supply	90 - Right	(K-L, 7-8)	LL(3)	7-8
	5	Folding Mirror	0 - Top	(I-J, 5-6)	J-K	6(1)
	6	IAM	0 - Top	(G-H, 7-8)	H(2)	7-8
	7	Moveable Mounts	270 - Left	(A-B, 7-8)	AA-A	8(1)
	8	Ultra HFR Camera	90 - Right	(E-F, 11-12)	F(1)	10-11
	9	Monochrome Macro OM	270 - Left	(I-J, 11-12)	H-I	11(2)
	10	Color Camera Controller	270 - Left	(G-H, 13-14)	F-G	13-14
	11	Camera Head	180 - Bottom	(E-F, 13-14)	F(1)	13-14
	12	Gimbaled Mirror	180 - Bottom	(A-B, 15-16)	B(1)	15-16
	13	High Magnification OM	270 - Left	(E-F, 17-18)	F(2)	17-18

A.7.2 Map- Experiment D



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A.8 Questionnaire

Questionnaire

This questionnaire is designed to receive feedback from you the user, on your interaction with the Optics Bench Experiment. The feedback you provide, will ultimately help in the design of the optics bench mapping/layout technique, as well as in the operational procedures, and how these procedures are developed. Please take the time to complete this form as thoroughly as possible. Your participation is greatly appreciated. Thanks!

Sex: Male/Female

Age: _____

Occupation: _____

If Student, please list degree program: _____

1. Which Mapping/Layout Technique did you prefer?

Please Circle one from each group:

- | | |
|-----------------------------|-------------------------|
| a. ABCs Labeling GRID LINES | a. Yellow Grids |
| b. ABCs Labeling BLOCKS | b. Without Yellow Grids |
| c. No Preference | c. No Preference |

2. Explanation of your preferences: _____

3. Which presentation method did you prefer?

- a. Directions
- b. Map and Directions

4. Explanation of your preferences: _____

5. At what level of difficulty would you rate the task?

1	2	3	4	5
Simple	Somewhat Simple	Neutral	Somewhat Difficult	Very Difficult

6. Clarity of Verbal Directions?

1	2	3	4	5
Vague	Somewhat Vague	Neutral	Somewhat Clear	Very Clear

7. Clarity of Written Directions?

1	2	3	4	5
Vague	Somewhat Vague	Neutral	Somewhat Clear	Very Clear

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8. Did you like having a recommended entry point?

Yes

No

Explanation: _____

9. Methodology/Technique you used to complete the task.

10. Comments

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APPENDIX B RAW DATA

B.1 Experiment A and B

Participant	A			Participant	B		
	Time	Errors	Order		Time	Errors	Order
1	4:32	0	1	1	4:11	0	2
2	12:53	1	1	2	7:10	1	3
3	8:11	1	1	3	7:20	0	4
4	8:17	0	1	4	6:05	0	3
5	10:07	0	1	5	6:31	0	2
6	17:57	7	1	6	5:26	3	4
7	5:33	0	2	7	8:26	0	1
8	6:29	0	3	8	6:29	3	1
9	4:38	0	4	9	4:47	3	1
10	5:52	1	3	10	6:36	0	1
11	6:00	0	4	11	6:55	1	1
12	5:02	0	2	12	5:57	1	1
13	3:48	1	2	13	4:21	1	3
14	7:57	0	2	14	6:31	0	4
15	3:59	0	4	15	4:57	1	2
16	6:55	0	3	16	8:09	0	2
17	9:45	3	3	17	6:04	3	4
18	6:58	1	4	18	5:20	0	3
19	7:36	1	3	19	7:26	1	4
20	4:19	0	4	20	4:33	0	3
21	6:49	0	3	21	8:14	0	2
22	5:22	0	4	22	6:06	0	2
23	10:08	0	2	23	8:05	0	3
24	4:24	1	2	24	4:26	0	4

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B.2 Experiment C and D

Participant	C			Participant	D		
	Time	Errors	Order		Time	Errors	Order
1	5:00	0	3	1	3:39	0	4
2	8:39	3	2	2	8:33	0	4
3	7:18	0	3	3	9:06	2	2
4	5:37	0	4	4	9:34	0	2
5	5:55	1	4	5	6:19	0	3
6	6:59	5	2	6	5:17	0	3
7	5:07	0	3	7	5:01	0	4
8	6:01	1	2	8	5:19	0	4
9	5:47	0	2	9	11:30	0	3
10	5:33	0	4	10	5:01	0	2
11	5:38	0	3	11	4:46	1	2
12	4:18	0	4	12	4:22	1	3
13	4:16	1	1	13	4:01	0	4
14	7:06	1	1	14	7:21	0	3
15	7:44	1	1	15	3:06	0	3
16	10:31	0	1	16	5:24	0	4
17	13:49	2	1	17	6:56	0	2
18	6:06	0	1	18	4:44	1	2
19	8:13	1	2	19	9:30	3	1
20	5:55	0	2	20	10:39	3	1
21	5:42	0	4	21	10:44	1	1
22	5:46	1	3	22	6:33	0	1
23	8:28	0	4	23	9:42	3	1
24	4:00	0	3	24	4:55	0	1

B.3 Sorted Data

A		B		C		D	
Order	Error (15 sec) + Time	Order	Error (15 sec) + Time	Order	Error (15 sec) + Time	Order	Error (15 sec) + Time
1	4:32	1	8:26	1	4:31	1	10:15
1	13:08	1	7:14	1	7:21	1	11:24
1	8:26	1	5:32	1	7:59	1	10:59
1	8:17	1	6:36	1	10:31	1	6:33
1	10:07	1	7:10	1	14:19	1	10:27
1	19:42	1	6:12	1	6:06	1	4:55
2	5:33	2	4:11	2	9:24	2	9:36
2	5:02	2	6:31	2	8:24	2	9:34
2	4:03	2	5:12	2	6:16	2	5:01
2	7:57	2	8:09	2	5:47	2	5:01
2	10:08	2	8:14	2	8:28	2	6:56
2	4:39	2	6:06	2	5:55	2	4:59
3	6:29	3	7:25	3	5:00	3	6:19
3	6:07	3	6:05	3	7:18	3	5:17
3	6:55	3	4:36	3	5:07	3	11:30
3	10:30	3	5:20	3	5:38	3	4:37
3	7:51	3	4:33	3	6:01	3	7:21
3	6:49	3	8:05	3	4:00	3	3:06
4	4:38	4	7:20	4	5:37	4	3:39
4	6:00	4	6:11	4	6:10	4	8:33
4	3:59	4	6:31	4	5:33	4	5:01
4	7:13	4	6:49	4	4:18	4	5:19
4	4:19	4	7:41	4	5:42	4	4:01
4	5:22	4	4:26	4	8:28	4	5:24

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APPENDIX C COUNTERBALANCING

1. ABCD 2. ACBD 3. ADCB 4. ADBC 5. ABDC 6. ACDB	7. BACD 8. BCAD 9. BCDA 10. BDAC 11. BDCA 12. BADC
13. CABD 14. CADB 15. CBDA 16. CBAD 17. CDAB 18. CDBA	19. DCAB 20. DCBA 21. DBAC 22. DBCA 23. DABC 24. DACB